NATIONAL BUREAU OF STANDARDS REPORT

10314

IMPACT TESTS ON GYPSUM WALLBOARDS

A Report
Prepared for
Office of Research and Technology
Department of Housing and Urban Development

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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PREFACE

The results of impact tests on gypsum wallboards on wood studs are presented in this report. The wallboards used in the tests were those products readily available commercially, and included products of several manufacturers.

This report is the first of two reports that deal with the impact energy absorption capacity of gypsum wallboards. The present report covers the results of tests of solid wallboards; and the second report, which will be issued when the test program is completed, will cover the results of tests of wallboards having a taped horizontal joint, as well as the results reported in this report.

All tests reported herein were carried out at the Structures Laboratory of the Building Research Division of the National Bureau of Standards.

TABLE OF CONTENTS

SI Conversion Units

In view of present accepted practice in this country in this technological area, common U.S. units of measurements have been used throughout this report. In recognition of the position of the USA as a signatory to the General Conference on Weights and Measures, which gave official status to the metric SI system of units in 1960 , the author assists readers interested in making use of the coherent system of SI units, by giving conversion factors applicable to U.S. units used in this paper.

Length	1 in =0.0254* meter
	1 ft =0.3048* meter
Area	1 in^2 =6.4516* x 10^{-4} $meter^2$
	1 ft^2 =0.09290 $meter^2$
Force	1 lb(lbf) = 4.448 newton
	1 kip = 4448 newton

*Exactly

1. INTRODUCTION

1.1 General

Gypsum wallboards used as an interior sheathing material in conventional wood-frame houses has virtually replaced lath and plaster on wood studs in recent years. However, while gypsum wallboards are widely used, sufficient engineering data are not available on impact strength of these wallboards. Thus, on the basis of the presentent state-of-the-art, the present Guide Criteria for the Design and Evaluation of Operation BREAKTHROUGH Housing Systems were developed.

The criteria covering the impact strength of interior space dividers (Criterion B.1.3.1.e)[1][1] is given as follows:

> Walls should resist the following loads with a maximum residual deflection not exceeding 10 percent of total maximum net deflection or $\ell/4000$, whichever is greater, measured 24 hours after removal of the superimposed load, and with no damage to surfaces, finishes, supports or subsystems:
>
> > An impact energy of 60 ft-lb, applied horizontally at any location five consecutive times, except in the case where the wall consists of stiffening elements supporting a surface cover. In the latter case, the wall should resist the 60 ft-lb impact energy delivered five

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[1] Numerals in bracket refer to corresponding items in Reference.

consecutive times to the surface cover coincident with the axis of the stiffening element and a 30 ft-lb impact energy delivered five consecutive times to the surface cover at any other location.

In specific cases, where local repairs of surface covers may be readily accomplished without leaving objectionable traces, using available materials and methods that do not require specialized skills, the 30 ft-lb impact energy may be reduced to 7.5 ft-lb.

The last stipulation reducing the impact energy from 30 ft-lb to 7.5 ft-lb was made to reflect the estimated performance of 1/2 in thick gypsum wallboards on studs spaced at 24 in center-to-center. It should be noted that this stipulation relates to the requirement on failure rather than to the requirement on residual deflection.

Accordingly, the purposes of this investigation were to develop engineering data on the impact energy absorption capacity of gypsum wallboards and to compare the performance of wallboard systems with the above stated criterion.

1.2 Gypsum Wallboard

Most gypsum wallboards available commercially are manufactured in compliance with ASTM C-36-68[2]. The counterpart Federal Specification is F.S. SS-L-30c.

Two types of gypsum wallboards are available for use in fire rated assemblies. These are identified by the ASTM Standard Specification as either Regular or Type X. The Regular-type wallboards have regular cores and the Type-X wallboards have fire-retardant cores. Within the Type-X category, some manufacturers produce two or more grades of wallboards improving the fire rating by varying the fiber content in the gypsum. However, this gradation within the Type-X category is not recognized by the ASTM Standard Specification.

2. DESCRIPTION OF TESTS

2.1 Test Program

Tests were conducted to establish a minimum level of performance of gypsum wallboards subjected to impact, using the evaluation method described in the ASTM E-72 Impact Load Test. The following three criteria were used to establish the level of performance.

CRITERION I: The level of impact energy which will not cause any observable damage on both faces of wallboard in five consecutive applications of a constant impact on one location.

CRITERION II: The level of impact energy which will cause damage on the unexposed face of wallboard but will not cause any observable damage on the exposed face in five consecutive applications of a constant impact on one location.

CRITERION III: The level of impact energy which will cause damage on both the exposed face and the unexposed face in one application of impact.

All tests were designed to establish these criteria for each group of specimens characterized by the same variables.

2.2 Test Variables

Three variables were used in designing the test program. They were the type of wallboard, either Regular (or Ordinary)[2] or Type X; the thickness of wallboard; and the spacing of studs. As mentioned previously, some manufacturers produce two or more grades of Type X wallboards; however, in this test program, all Type-X wallboards were considered as one grade.

Although a wide range of partition assemblies can be made by combining the above variables in different ways, only those partition assemblies found in conventional house construction were selected for testing. Reference was made to the FHA Minimum Property Standards for one and two living

[2] In this report, Ordinary-type refers to Regular-type specified in ASTM C-36-68.

units[3] in determining the thickness of wallboards and the spacing of studs. The matrix format of table 1 illustrates the various combinations of variables used for the tests reported herein.

2.3 Test Specimen

The test specimens were fabricated using a single full-sized sheet of wallboard (4x8 ft) nailed on 2x4 in (nominal dimensions) wood-stud frames. The layout of the frame is shown in figure 1. To simulate walls or partitions having wallboards on both side, 4x1/8 in plywood strips were nailed on the opposite side of the frame. This scheme facilitated visual inspection of the backside of the wallboard during the test.

The wallboard was nailed to the frame by 1 3/8 in long threaded wallboard nails. The nails were spaced at 6 in o.c. along the top and bottom plates, and at 8 in o.c. on the vertical studs. All nails along the edges of the panel had a minimum edge distance of 3/8 in.

Based on the variables used the test panels were designated as follows:

3/8 - ORD - 16
1/2 - ORD - 24

1/2	-	ORD	-	16
1/2	-	X	-	24
1/2	-	X	-	16
5/8	-	ORD	-	24
5/8	-	X	-	24.

The fraction of an inch indicates the thickness of the wallboard. ORD and X denote the type of the wallboard, Ordinary (Regular type) and Type X, respectively. The last two numbers represent the spacing of the studs.

2.4 Test Setup

The test setup, which is similar to the one suggested in ASTM E-72 Test, is illustrated in figure 2. It consisted of a test frame, a 60 lb sandbag and a bag-release device mounted on a hand-operated forklift. The test specimen was placed in a vertical position to simulate service conditions. Impact was delivered to the specimen by the sandbag as a pendulum released from a predetermined height. The specification of the bag conformed to the description given in ASTM E-72 sect. 12.2.2.1, with the exception that it was made of a heavy canvas instead of Indian-tanned lace leather. For each drop the bag was released by suddenly opening the hinged doors of the bag holding device, thus eliminating wobbling of the bag. A photograph showing the actual test setup is shown in figure 3.

The impact was delivered between two studs at each test section. The magnitude of impact was varied by adjusting the height of drop of the bag. The height was measured from the point of impact of the center of gravity of the bag where it strikes the test section to this same point when the bag was in the raised position (fig. 2).

By halving the test panel vertically, the impact was delivered to two locations, each measured 24 in from the upper and the lower edge of the panel, respectively (positions A and B in fig. 2). Thus, it was possible to conduct four tests at 2x2 grid points on panels which had studs spaced at 24 in o.c. and six tests at 3x2 grid points on panels which had studs spaced at 16 in o.c.

2.5 Test Procedure

To establish Criterion I and II, as defined in sect. 2.1, five impacts of a constant magnitude were delivered to one point. For Criterion III a single impact was delivered. Only one test was made at each test section, eventhough a tested section appeared without any damage.

In evaluating each criterion, the initial magnitude of the impact for a test section was selected arbitrarily for each

group of identical specimens. In subsequent tests the magnitude of impact was determined by the preceding one.

In order to minimize the number of tests, the staircase (or "up-and-down") method of testing[4] was followed. This method of testing allowed a faster convergence to the critical impact strength for each criterion.

3. TEST RESULTS AND DISCUSSIONS

3.1 Test Data

A total of 317 tests was made in the present test series. The frequency distribution of tests according to heights of drop of the sandbag are shown for each type of test panel in figures 4 through 10. The number of tests made to establish the three criteria for each type ranged from 32 tests for test panels 1/2-ORD-24 to 70 tests for test panels 1/2-ORD-16. For the latter, which was the first group tested, a large number of tests were needed as no precedent test data were available for guidance. With the exception of tests on panels 1/2-ORD-16, an average of about 41 tests was required to evaluate the criteria.

The number of tests made to establish each criterion for each type of test panel is indicated in figures 4 through 10. The heights and the corresponding magnitudes of impact energy are listed in table 2. It is seen in the table that the critical impact strengths for Criterion II and Criterion III are about two and four times that for Criterion I. These relationships as expressed by the ratio of impact strength for one criterion to that for the other two are shown in figures 11 and 12. The mean of the ratios of the impact strength for Criterion I to Criterion III

and the same for Criterion II to III are 0.264 and 0.505, respectively. Thus, the test results indicate that, if the impact strength for any one criterion is established, the other two criteria can be derived by using the ratios of the impact strengths.

3.2 Effect of Type of Wallboard on Impact Strength

Since the fiber content is greater in Type X wallboards than in Regular wallboards, it is expected that the impact strength of Type X wallboards would be greater than that of Regular wallboards. The variation in strength can be seen in table 3, in which the ratios of the impact strength of Type X wallboards to that of Regular wallboards are listed. It is apparent that, in all cases, the strength of the Type X wallboards exceeded the strength of the Regular wallboards. The increase in the strength ranged from 17 percent to as much as 133 percent. When the averages of increase in the strength are compared among the three ratios listed in table 3, the amount of the increase in the strength is inversely proportional to the stiffness (EI/ℓ) of the panel, where E is the modulus of elasticity, I is the moment of inertia of the cross section of the wallboard and ℓ is the span between two supports (or the spacing of studs).

3.3 Effect of Thickness of Wallboard and Spacing of Studs on Impact Strength

Both the thickness of wallboard and the spacing of studs simultaneously influence the impact strength of the wallboard through the stiffness. Thus, the effects of these two variables on the impact strength are considered together.

In flexural members the deflection is governed by the stiffness of the member. As a result, under external forces a flexible member would deflect more than a stiff member. Consequently, the work done during deflection by the external forces or the energy stored in the member is greater in the flexible member than the stiff member.

For members of the same material, the stiffness can be expressed as the ratio of the moment of inertia, I, to the span, ℓ, since the modulus of elasticity, E, is constant. Since the energy absorption capacity is inversely proportional to the stiffness, and considering a unit width of the wallboard, the energy absorption capacity can be expressed as a function of ℓ/t^3, where t is the thickness of the wallboard.

In figure 13 the impact strength for each criterion of the wallboards tested are plotted as a function of the ratio of

ℓ/t^3. The results of wallboards of the Regular type are connected by solid lines; and those of Type X are connected by broken lines. It is seen in the figure that, as the ratio of ℓ/t^3 becomes smaller, the impact strength increases rapidly. On the other hand, beyond the ratio of ℓ/t^3 equal to 200, any further increase in this ratio does not result in appreciable decrease in the impact strength. This figure also shows that for identical assemblies of test panels, Type X wallboards have greater impact strength than Regular wallboards.

For the case where only the thickness of wallboards is considered, table 4 lists the ratios of the impact strengths of two different thicknesses of wallboards. It is apparent that a substantial increase in the strength results from an increase in thickness. On the average, an increase in the thickness of wallboard by 1/8 in will yield an increase in the impact strength of about 90 percent.

The impact strength as affected only by the spacing of studs is shown in table 5. Listed in the table are the ratios of two impact strengths of wallboards, one having studs spaced at 16 in o.c. and the other having studs spaced at 24 in o.c. It is seen that the increase in the strength by decreasing the stud spacing was not as great as was the

increase in the strength by increasing the thickness. On the average, reducing the spacing of studs from 24 in o.c. to 16 in o.c. increased the impact strength by 22 percent. These results (tables 4 and 5) suggest that increasing the thickness of wallboards is more effective in increasing the impact strength than is reducing the spacing of studs.

4. DESIGN CONSIDERATION AND TECHNIQUES OF EVALUATING IMPACT STRENGTH

4.1 Design Consideration

Three criteria were used to establish the level of performance of wallboards against impact (refer to sect. 2.1). Among the three, Criterion II is the one specified in the present design and evaluation criteria for Operation BREAKTHROUGH Housing Systems. From the user's point of view, this criterion is reasonable in that five consecutive applications of constant impact would cause damage only to the unexposed face of the wallboard. As long as no damage appears on the exposed face, the function of the wallboard is not impaired. Furthermore, in real situations it is highly improbable that one location would be subjected to impact for five times. Thus, requiring the wallboards to perform at a level more severe than Criterion II would be unrealistic. However, the choice between Criterion I and Criterion II must be left to the user and the designer. On the other hand, if the magnitude of impact is so high that it causes damage on both surfaces of the wallboard, Criterion III provides the information.

The intent of the BREAKTHROUGH Guide Criterion B.1.3.1.(e)[1] (also refer to sect. 1.1) is to provide a minimum resistance

against human impact on partitions. At present, the magnitude of impact exerted on partitions by a person being pushed against it has not been defined. The purpose of 7.5 ft-lb impact specified in the BREAKTHROUGH Guide criterion is to include partition assemblies which are being used in conventionally built houses. This value is indicated on figure 14 with Criterion II of Regular wallboards as a limiting value. In this figure the shaded area (acceptable region) includes most partition assemblies found in current practice. The one assembly which would not be included in the shaded area is 3/8 in wallboards on studs space at 16 in o.c. The usefulness of figure 14 is that it enables one to estimate an expected level of wallboard partition systems performance which does not conform to present practice, i.e., spacing the studs at 16 or 24 in o.c. for ratios of ℓ/t^3 between 100 and 200.

4.2 Techniques of Evaluating Impact Strength

The impact strengths of different assemblies of gypsum-wallboard panels were presented and discussed in sect. 3.1. It was shown that the impact strength for one criterion could be used to express the strength of the same panel for the other two criteria. Thus, if the strength for one criterion is evaluated, the others can be obtained by multiplying appropriate factors.

It was found in the present series of tests that, of the three criteria, Criterion III was the most convenient one to establish within a minimal time frame for the sake of expediency. Thus, the impact strength for Criterion III may be evaluated. Upon establishing the strength for Criterion III and by taking 25 percent and 50 percent of the impact strength for Criterion III, conservative estimates of the strength for Criterion I and II can be made.

5. CONCLUSIONS

An investigation was conducted to evaluate the impact strength of gypsum wallboards nailed on wood studs. A total of 317 tests was made on various partition assemblies. Three levels of performance of gypsum wallboards against impact were evaluated. The following conclusions are based on the results of this investigation:

1) For the criterion that five consecutive applications of impact at one location would limit damages only to the unexposed face and leave no trace of damage on the exposed face (Criterion II), the impact strength of most partition assemblies used in conventionally-built houses would exceed the 7.5 ft-lb limiting value specified in the criteria for the design and evaluation of Operation BREAKTHROUGH Housing Systems. The assembly which would not meet the 7.5 ft-lb criterion is that comprised of 3/8 in wallboard nailed on studs spaced at 16 in o.c.

2) Type X wallboard has greater impact strength than Regular wallboard. The increase in the strength of Type X wallboards over that of Regular wallboards is inversely proportional to the stiffness of the wallboard on the framing members.

3) The impact strength can be increased more effectively by increasing the thickness of wallboard, rather than by decreasing the spacing of studs.

4) The amount of impact energy which will cause damage to both faces of the wallboard with one application is twice the amount which will cause damage to only the

unexposed face with five applications of a constant impact on one location and is four times the amount which will not cause any observable damage on either faces with five applications of a constant impact on one location.

6. ACKNOWLEDGMENTS

The tests reported herein were carried out at the Structures Laboratory of the National Bureau of Standards. The tests were performed by Messrs. F. Rankin, J. Seiler and L. Payton. Their assistance is appreciated.

The author wishes to thank Dr. E. V. Leyendecker, Messrs. Thomas W. Reichard and Charles W. Yancey of the Structures Section, for reviewing the report.

7. TABLES AND FIGURES

Test Variables (1) / Test Variables (2) and (3)		Thickness of Wallboards (in)		
		$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$
Type of Wallboard	ORDINARY*	+	+	+
	TYPE - X	Not Used in Practice	+	+
Spacing of Studs	16 in c/c	+	+	Not Used in Practice
	24 in c/c	Not Used in Practice	+	+

* Ordinary referes to regular type of wallboards as defined in ASTM C-36-68.

TABLE 1 TEST PROGRAM

SPECIMEN	CRITERION			CRITERION		
	I	II	III	I	II	III
	Height of Drop (in)			Energy Delivered (lb-ft)		
$\frac{3}{8}$ - ORD - 16	$\frac{3}{4}$	1	2	3.75	5.00	10.00
$\frac{1}{2}$ - ORD - 24	$\frac{3}{4}$	$1\frac{1}{2}$	$2\frac{3}{4}$	3.75	7.50	13.75
$\frac{1}{2}$ - ORD - 16	1	2	4	5.00	10.00	20.00
$\frac{1}{2}$ - X - 24	$1\frac{3}{4}$	$2\frac{3}{4}$	$5\frac{3}{4}$	8.75	13.75	28.75
$\frac{1}{2}$ - X - 16	$1\frac{3}{4}$	3	$6\frac{3}{4}$	8.75	15.00	33.75
$\frac{5}{8}$ - ORD - 24	$1\frac{1}{2}$	4	7	7.50	20.00	35.00
$\frac{5}{8}$ - X - 24	$1\frac{3}{4}$	5	10	8.75	25.00	50.00

TABLE 2 TEST RESULTS

CRITERIA / STRENGTH RATIO	Cri I	Cri II	Cri III	AVERAGE
$\frac{1/2 - X - 24}{1/2 - ORD - 24}$	2.33	1.83	2.09	2.08
$\frac{1/2 - X - 16}{1/2 - ORD - 16}$	1.75	1.50	1.69	1.65
$\frac{5/8 - X - 24}{5/8 - ORD - 24}$	1.17	1.25	1.43	1.28

TABLE 3 EFFECT OF TYPE OF WALLBOARD ON IMPACT STRENGTH

CRITERIA / STRENGTH RATIOS	Cri I	Cri II	Cri III	AVERAGE
$\frac{1/2 - ORD - 16}{3/8 - ORD - 16}$	1.33	2.00	2.00	1.78
$\frac{5/8 - ORD - 24}{1/2 - ORD - 24}$	2.00	2.67	2.55	2.41
$\frac{5/8 - X - 24}{1/2 - X - 24}$	1.00	1.82	1.74	1.52

TABLE 4 EFFECT OF THICKNESS OF WALLBOARD ON IMPACT STRENGTH

STRENGTH RATIOS \ CRITERIA	Cri I	Cri II	Cri III	AVERAGE
1/2 - ORD - 16 / 1/2 - ORD - 24	1.33	1.33	1.45	1.37
1/2 - X - 16 / 1/2 - X - 24	1.00	1.09	1.17	1.07

TABLE 5 EFFECT OF SPACING OF STUDS ON IMPACT STRENGTH

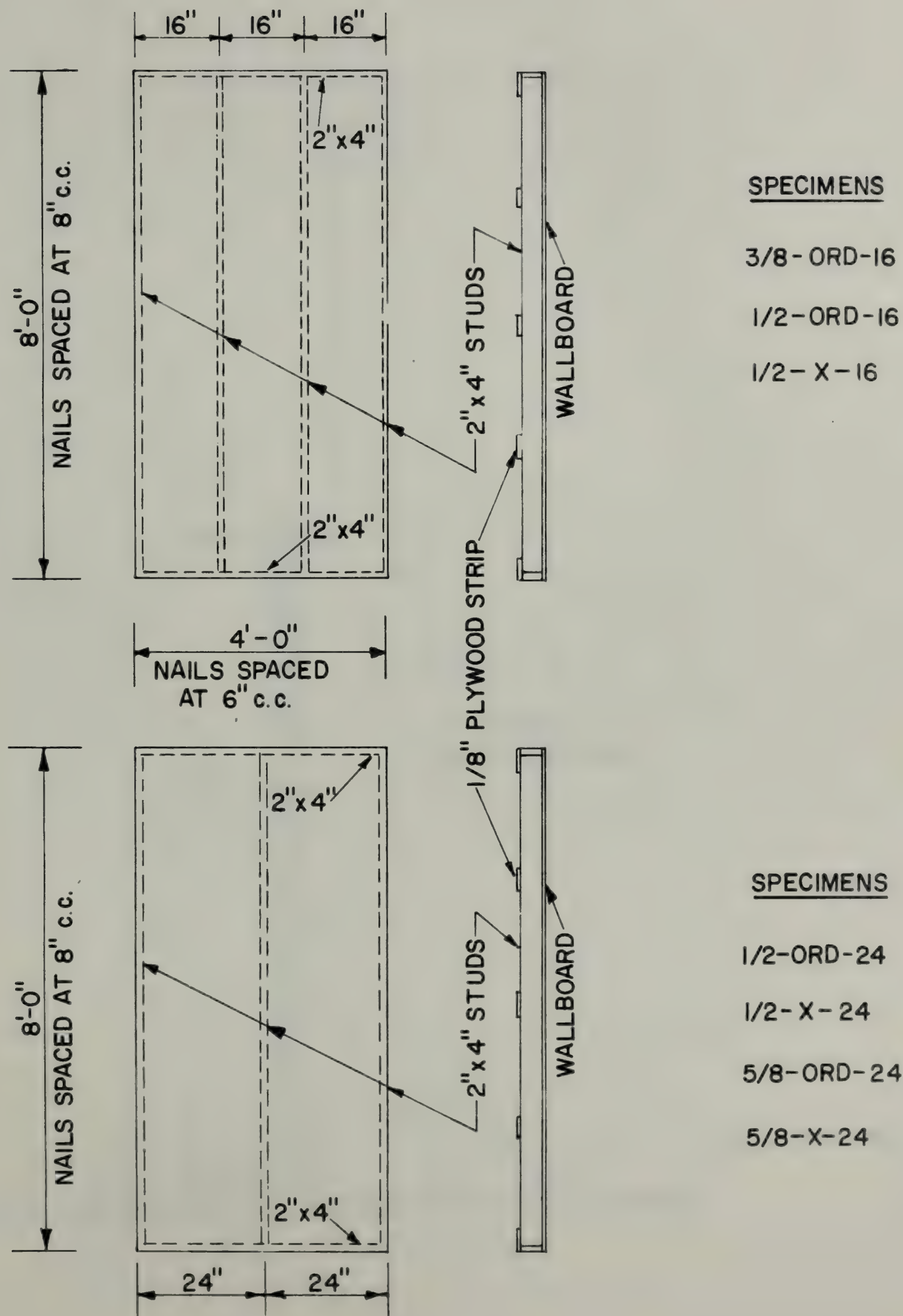

FIGURE 1 TEST PANELS

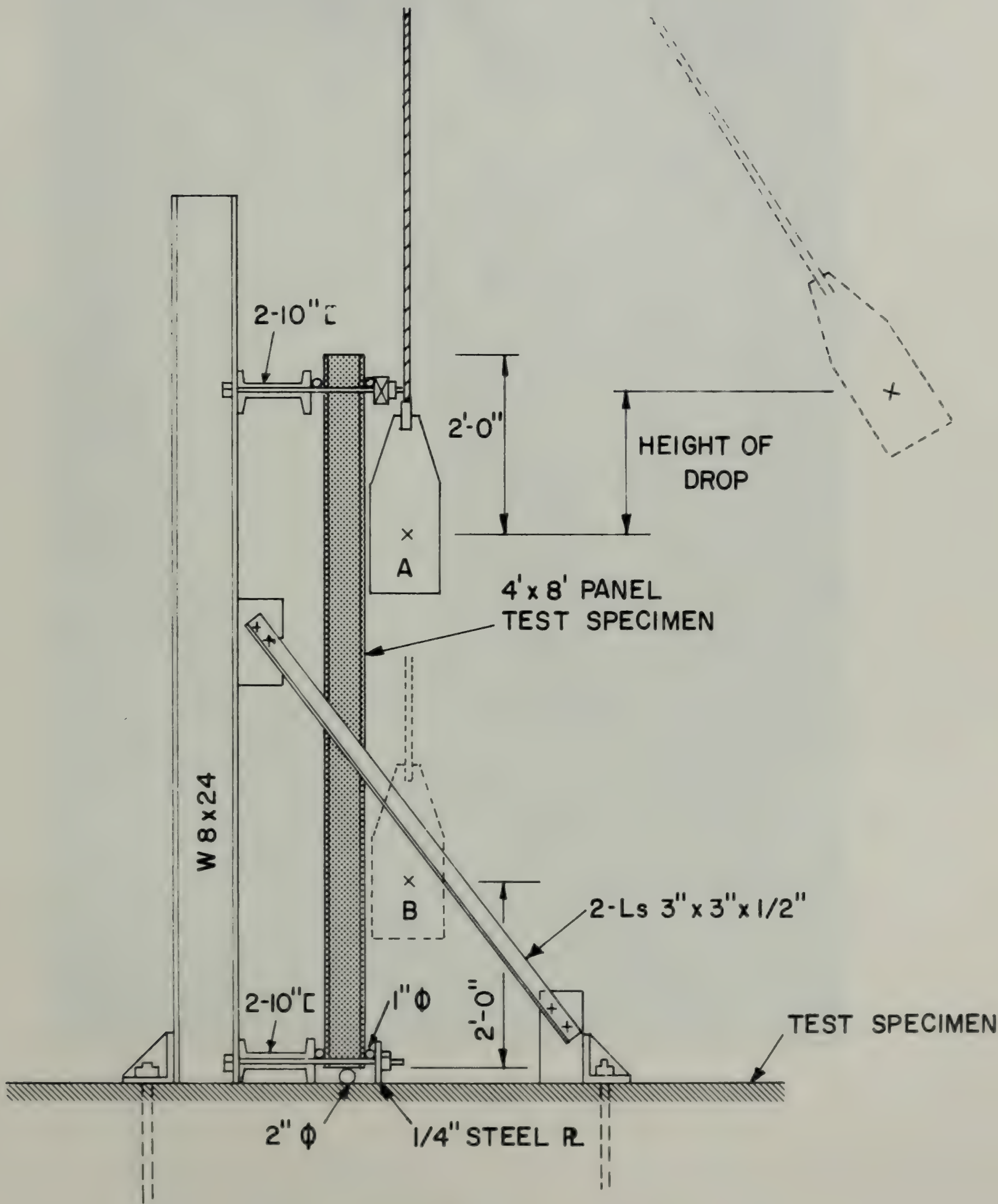

FIGURE 2 TEST SETUP

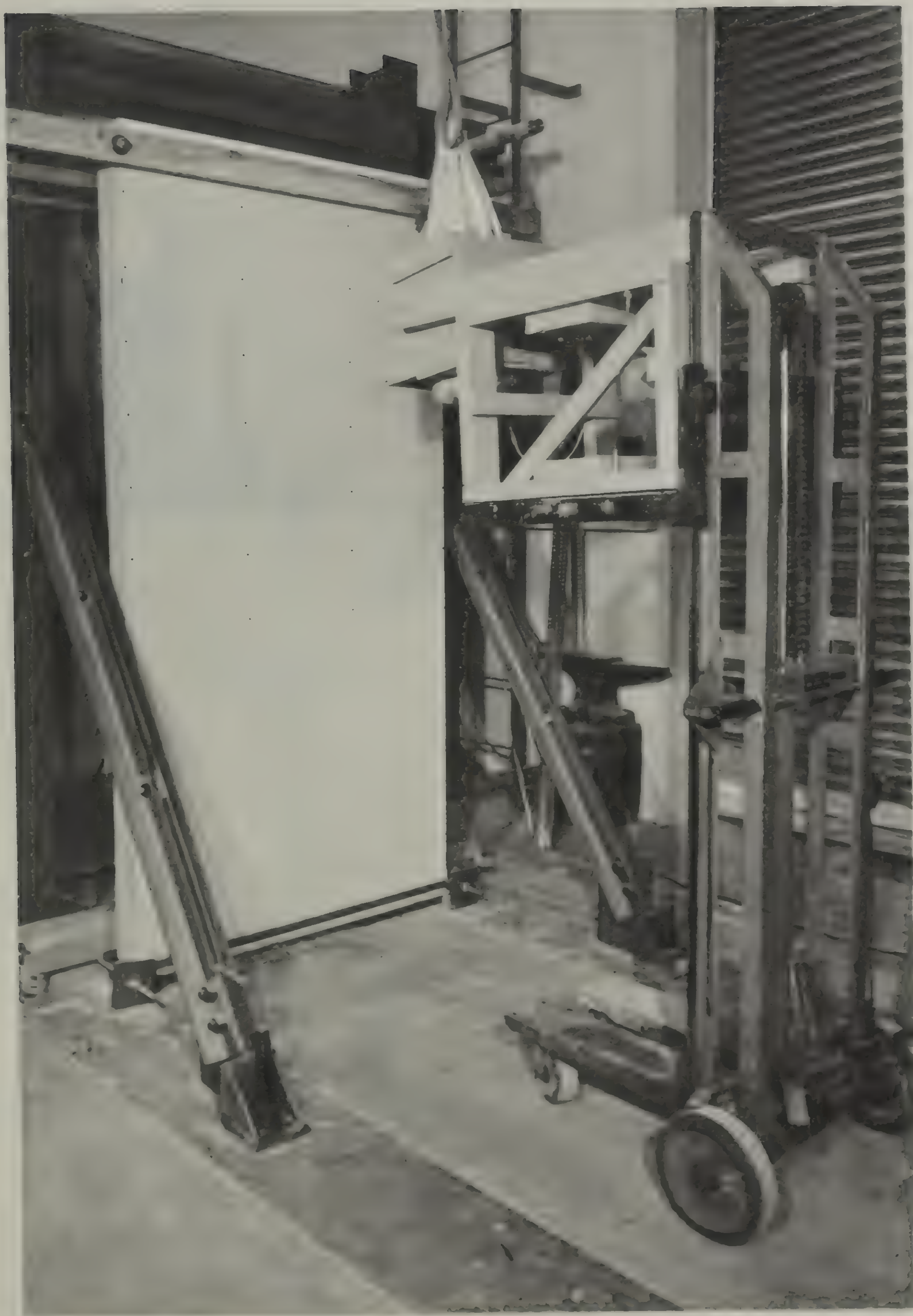

FIGURE 3 PHOTOGRAPH OF TEST SETUP

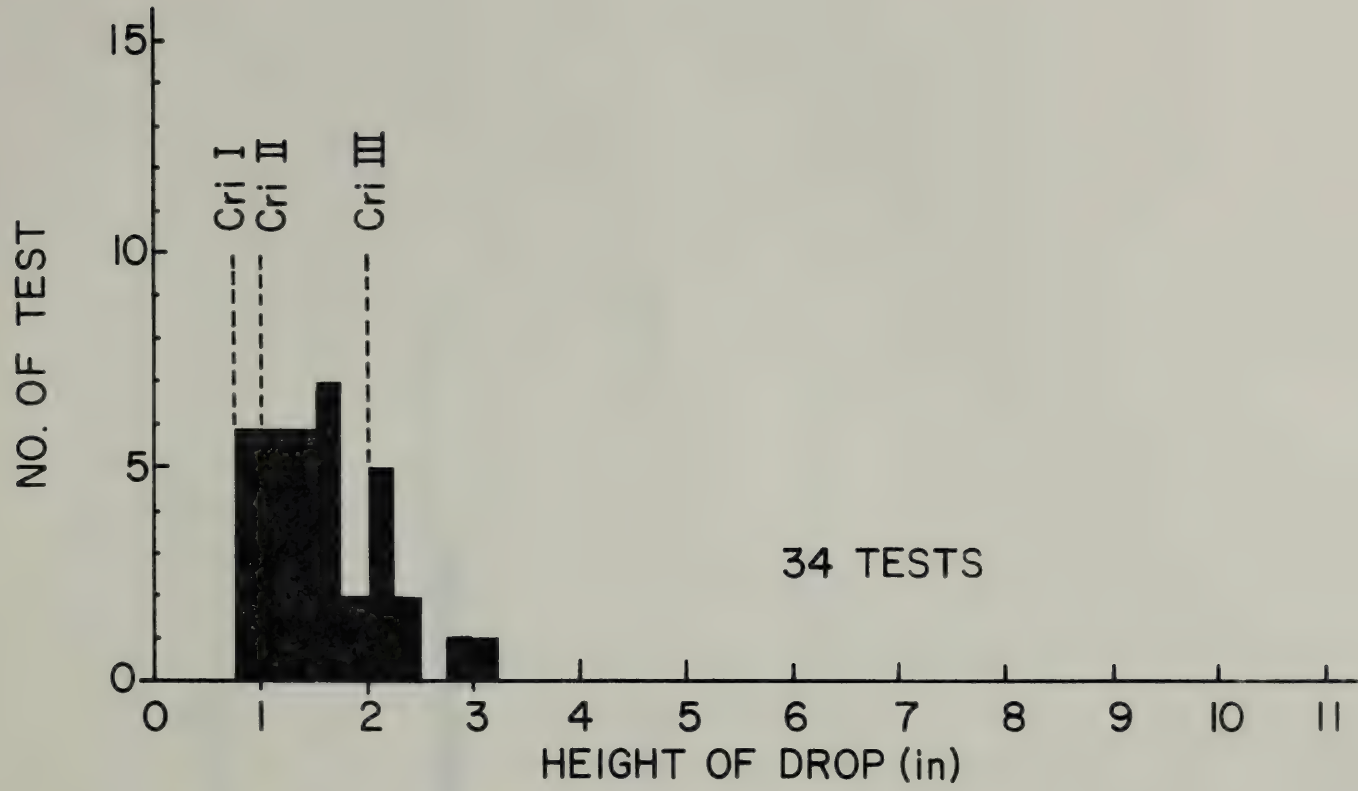

FIGURE 4 DISTRIBUTION OF TESTS OF
TEST PANELS 3/8 - ORD - 16

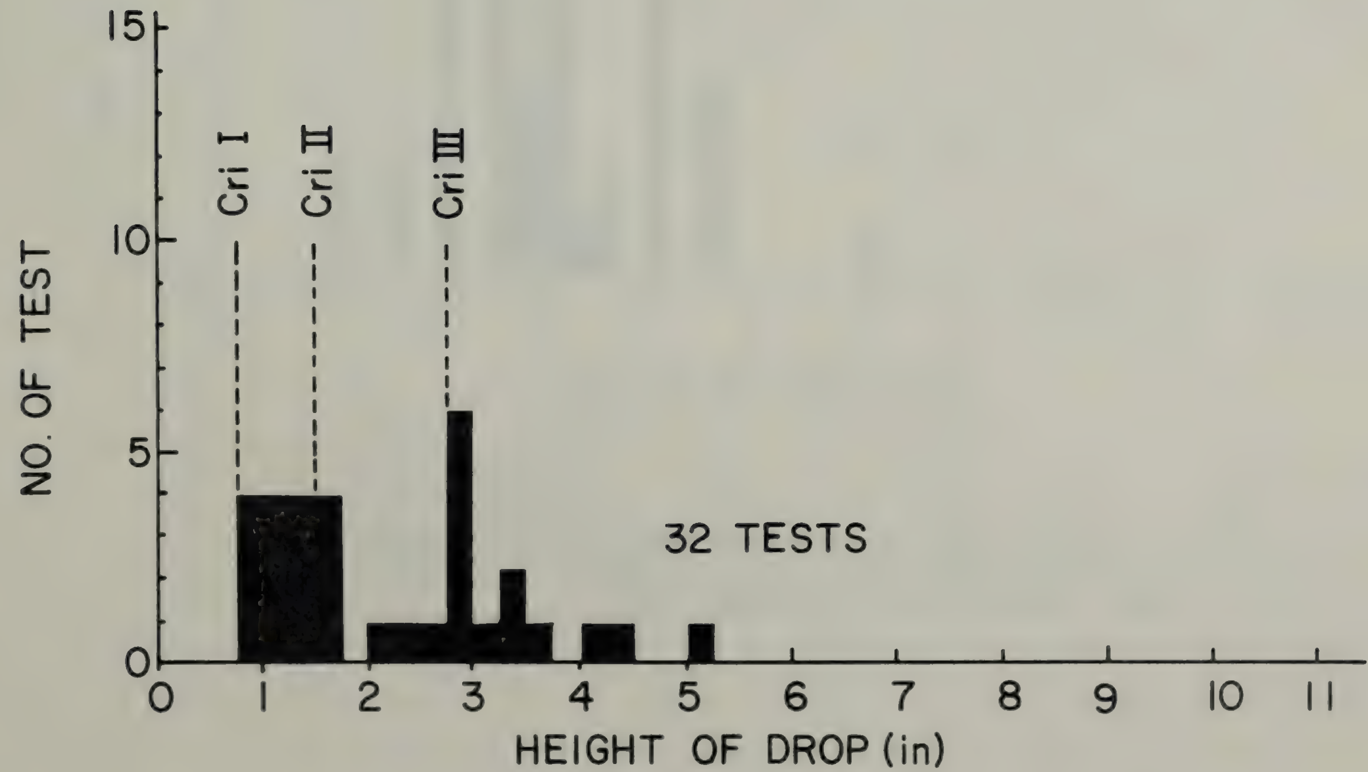

FIGURE 5 DISTRIBUTION OF TESTS OF
TEST PANELS 1/2 - ORD - 24

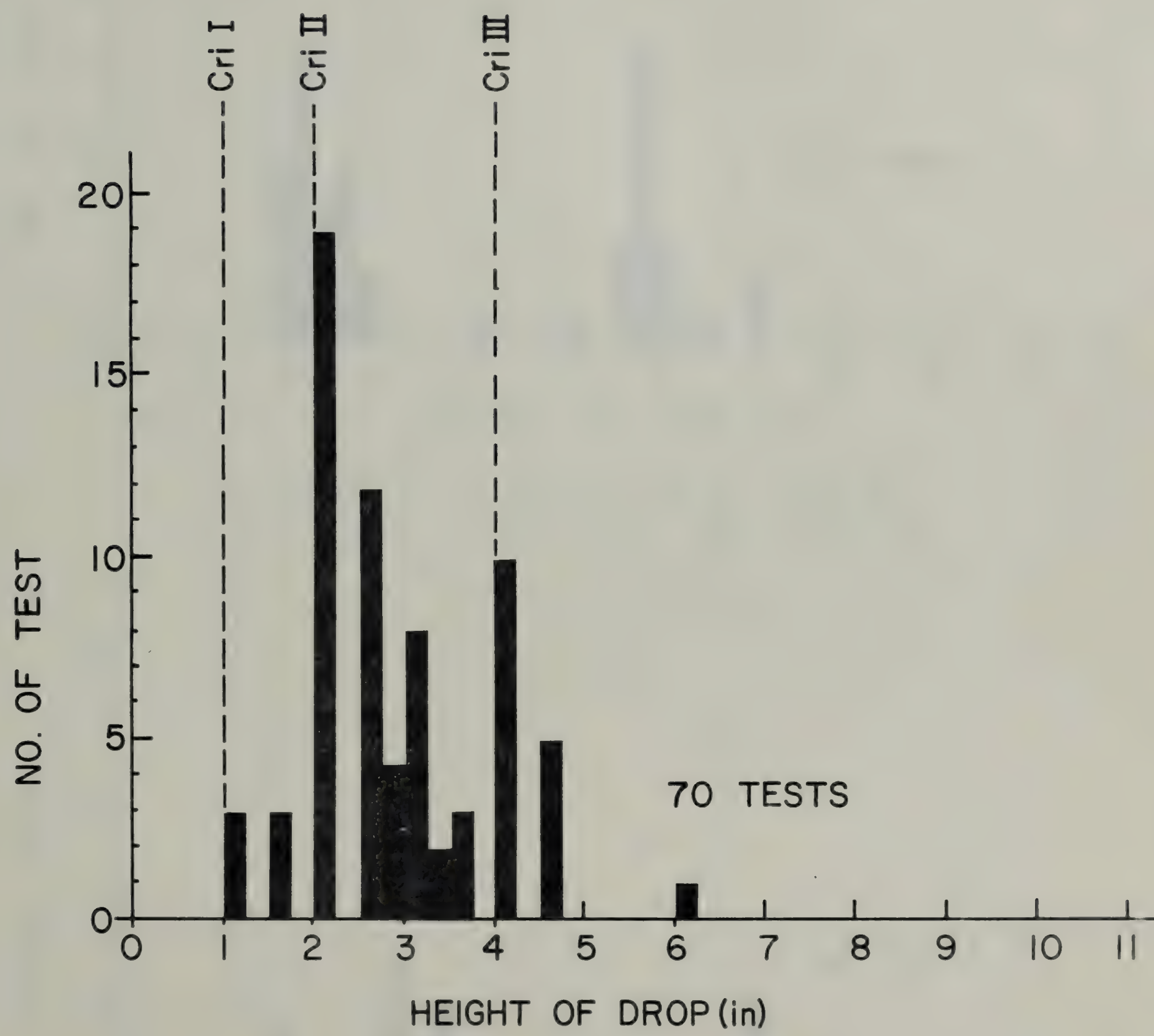

FIGURE 6 DISTRIBUTION OF TESTS OF
TEST PANELS 1/2 - ORD - 16

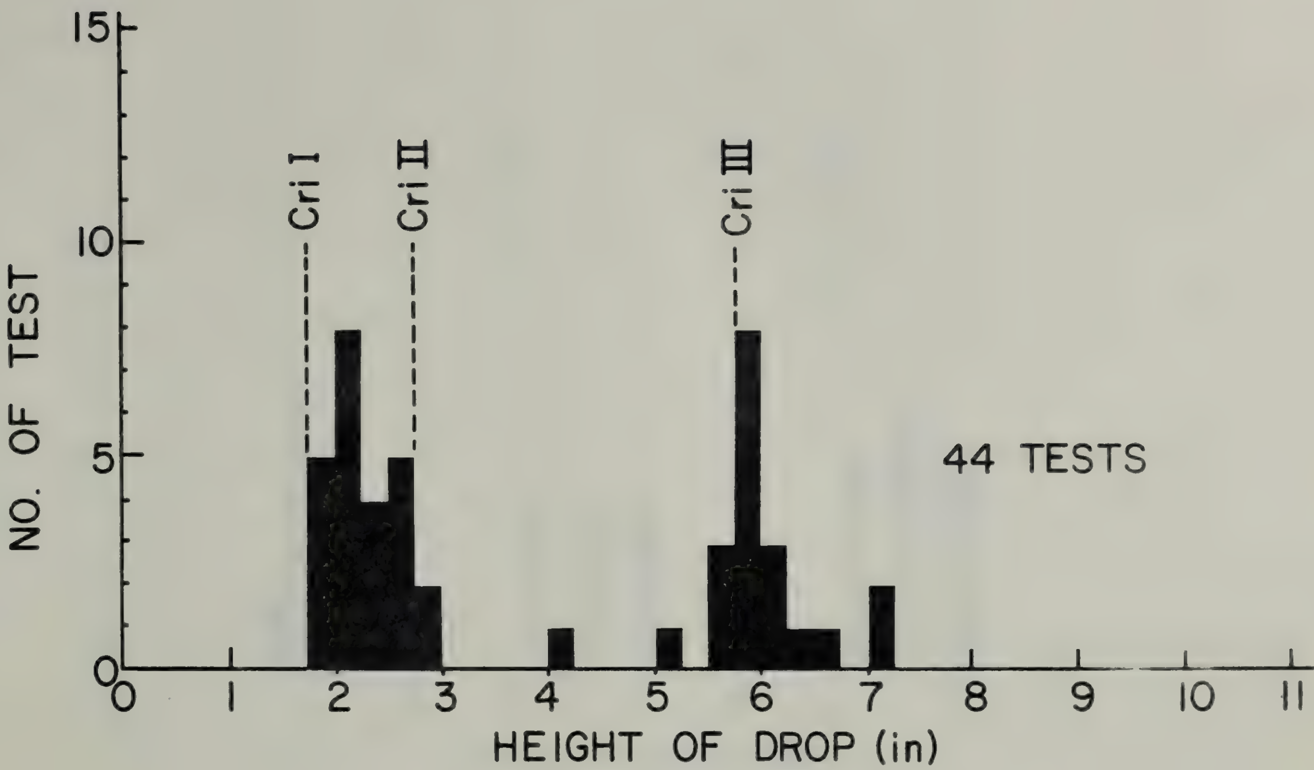

FIGURE 7 DISTRIBUTION OF TESTS OF TEST PANELS 1/2 - X - 24

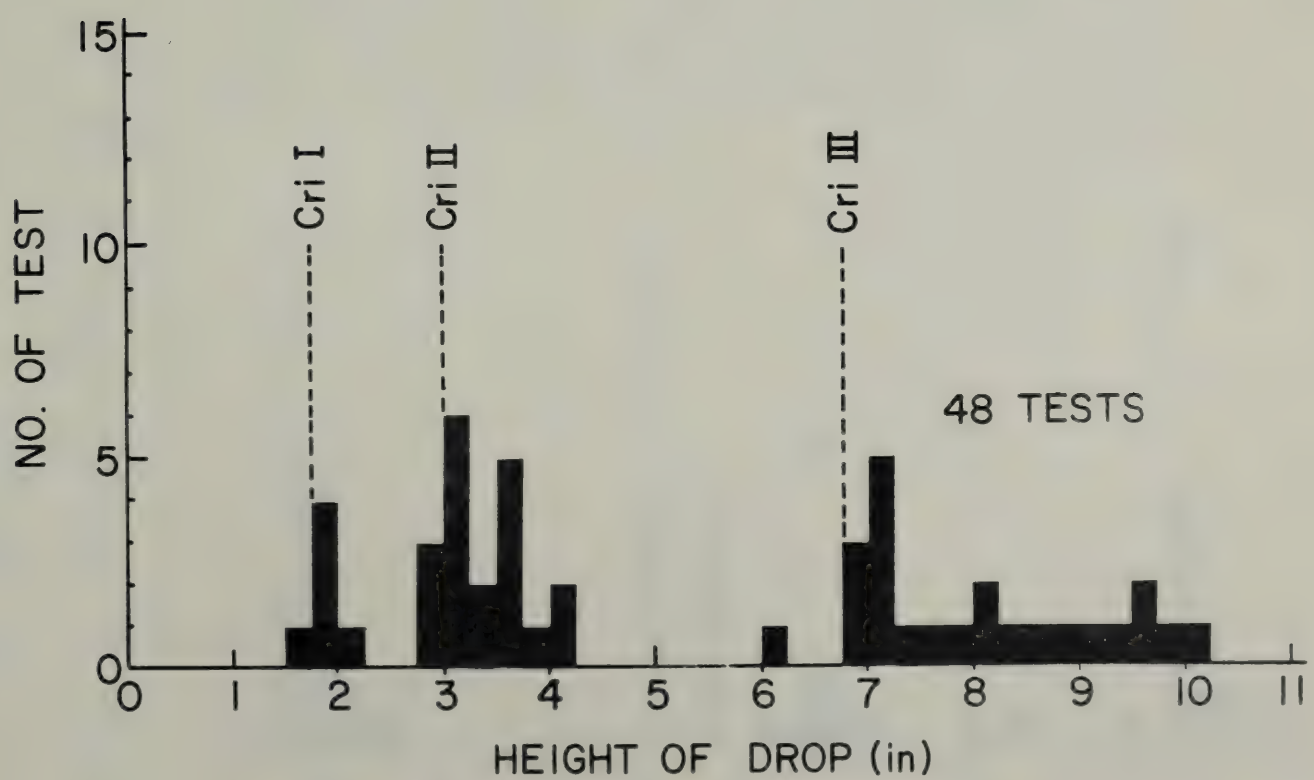

FIGURE 8 DISTRIBUTION OF TESTS OF TEST PANELS 1/2 - X - 16

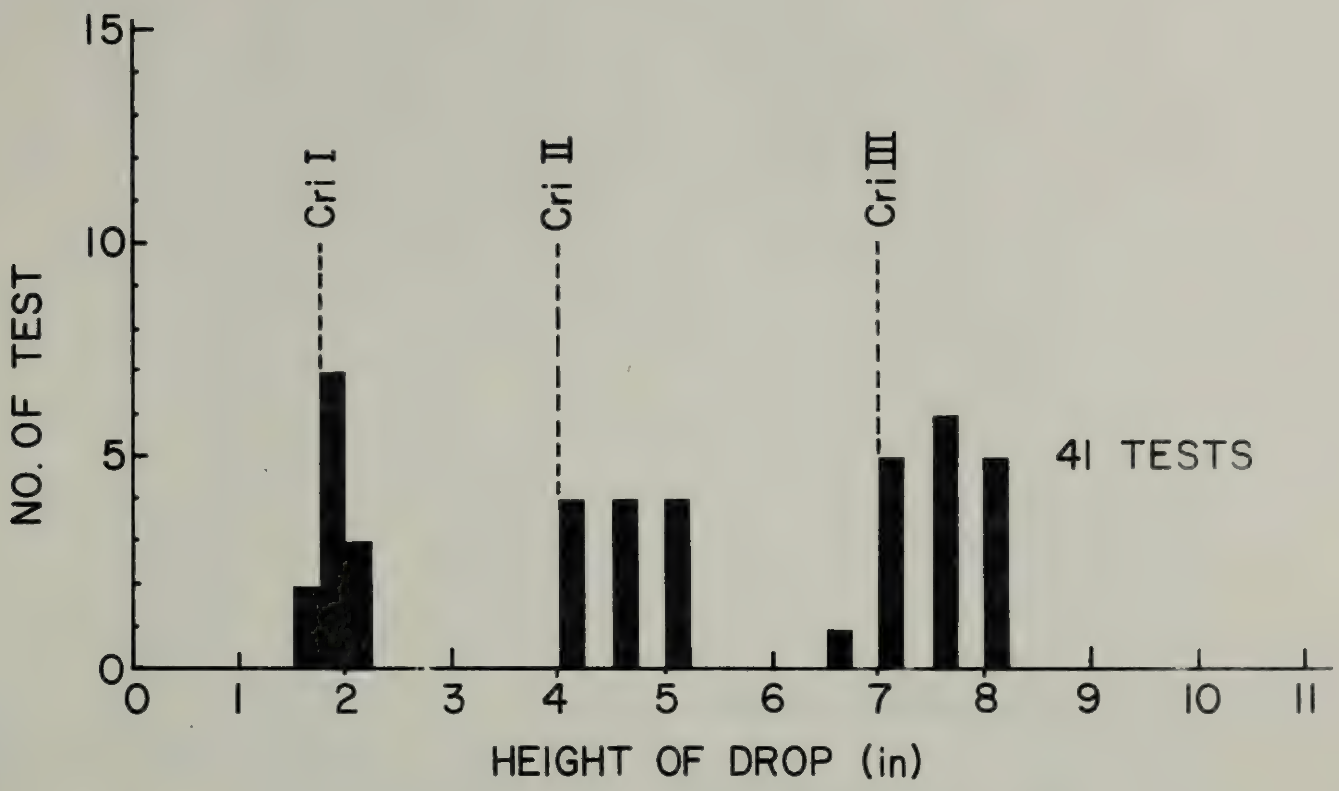

FIGURE 9 DISTRIBUTION OF TESTS OF TEST PANELS 5/8 - ORD - 24

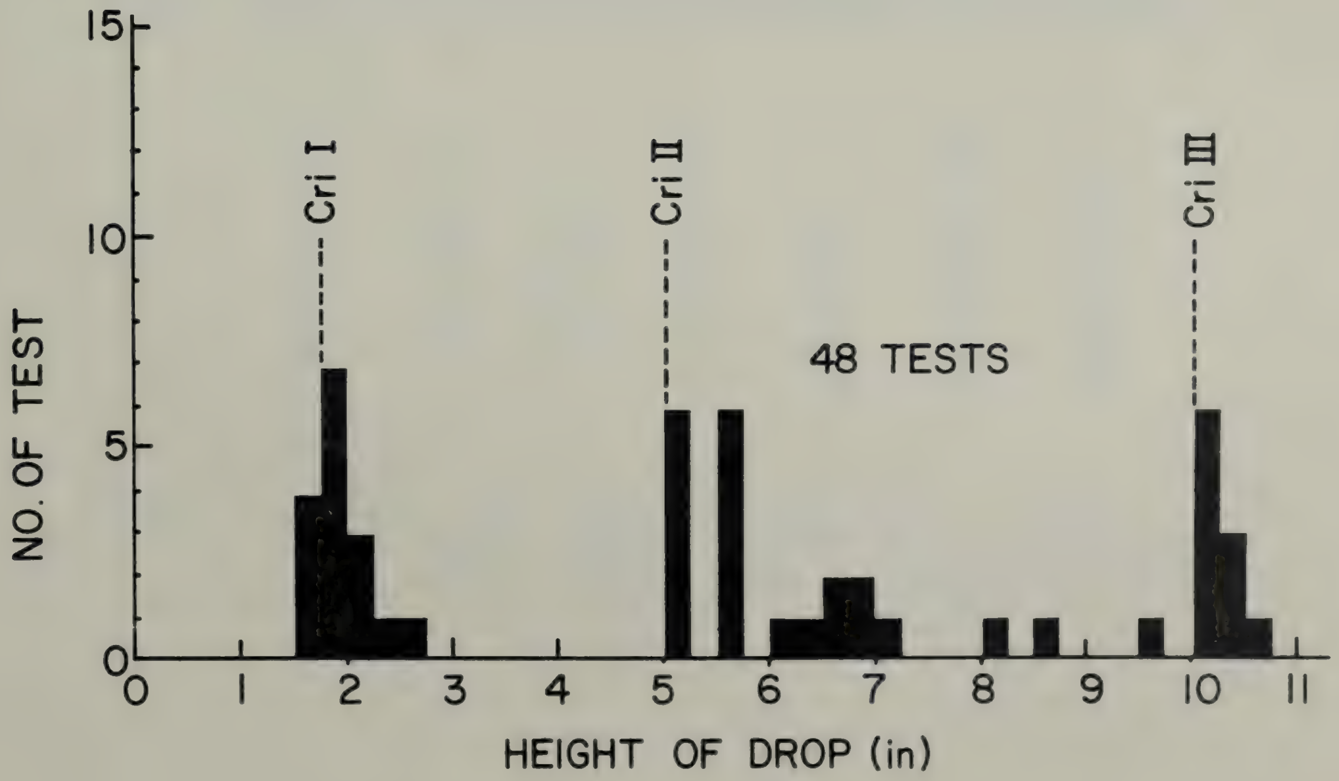

FIGURE 10 DISTRIBUTION OF TESTS OF TEST PANELS 5/8 - X - 24

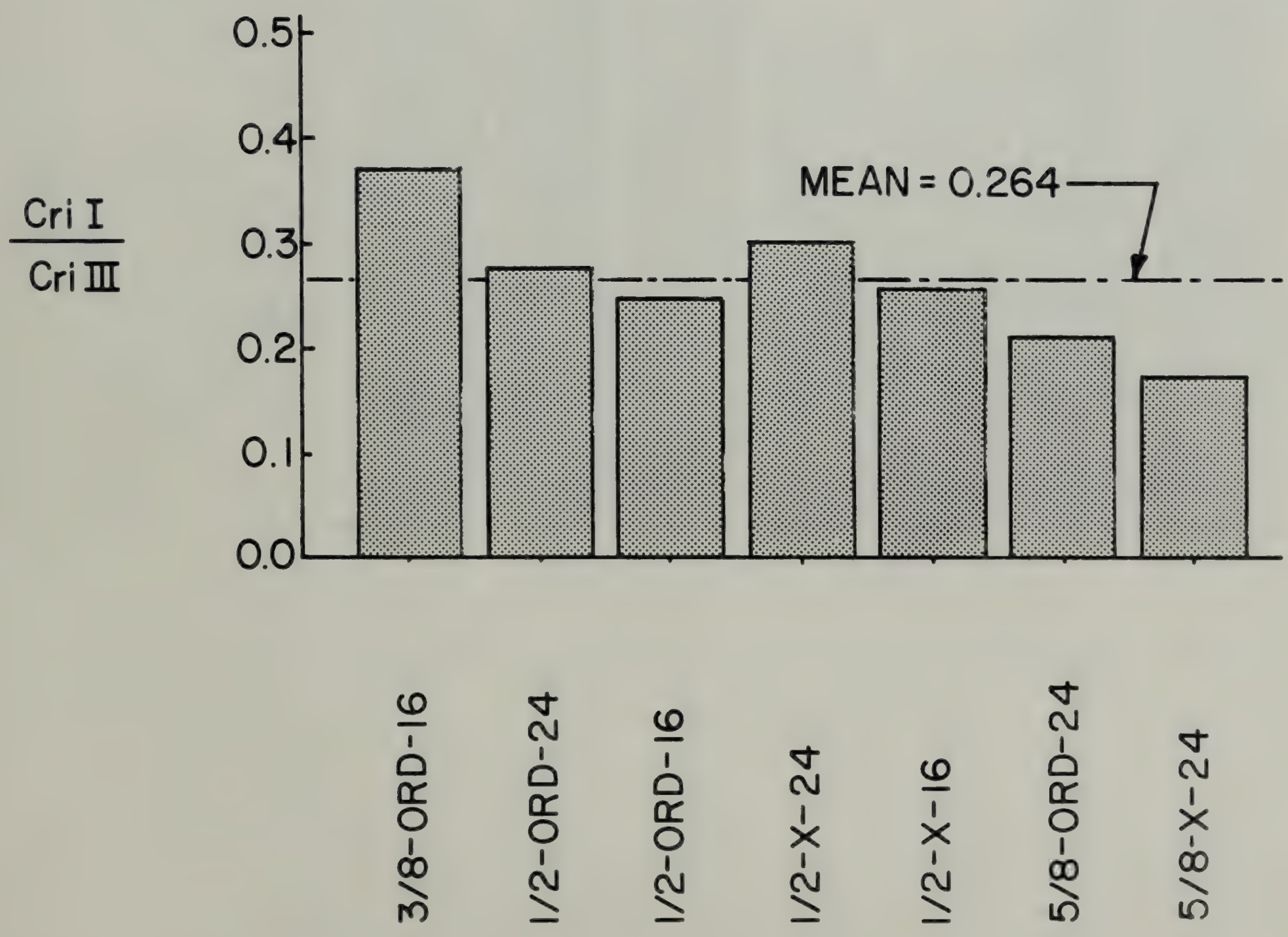

FIGURE 11 RATIOS OF IMPACT STRENGTH FOR CRITERION I TO IMPACT STRENGTH FOR CRITERION III

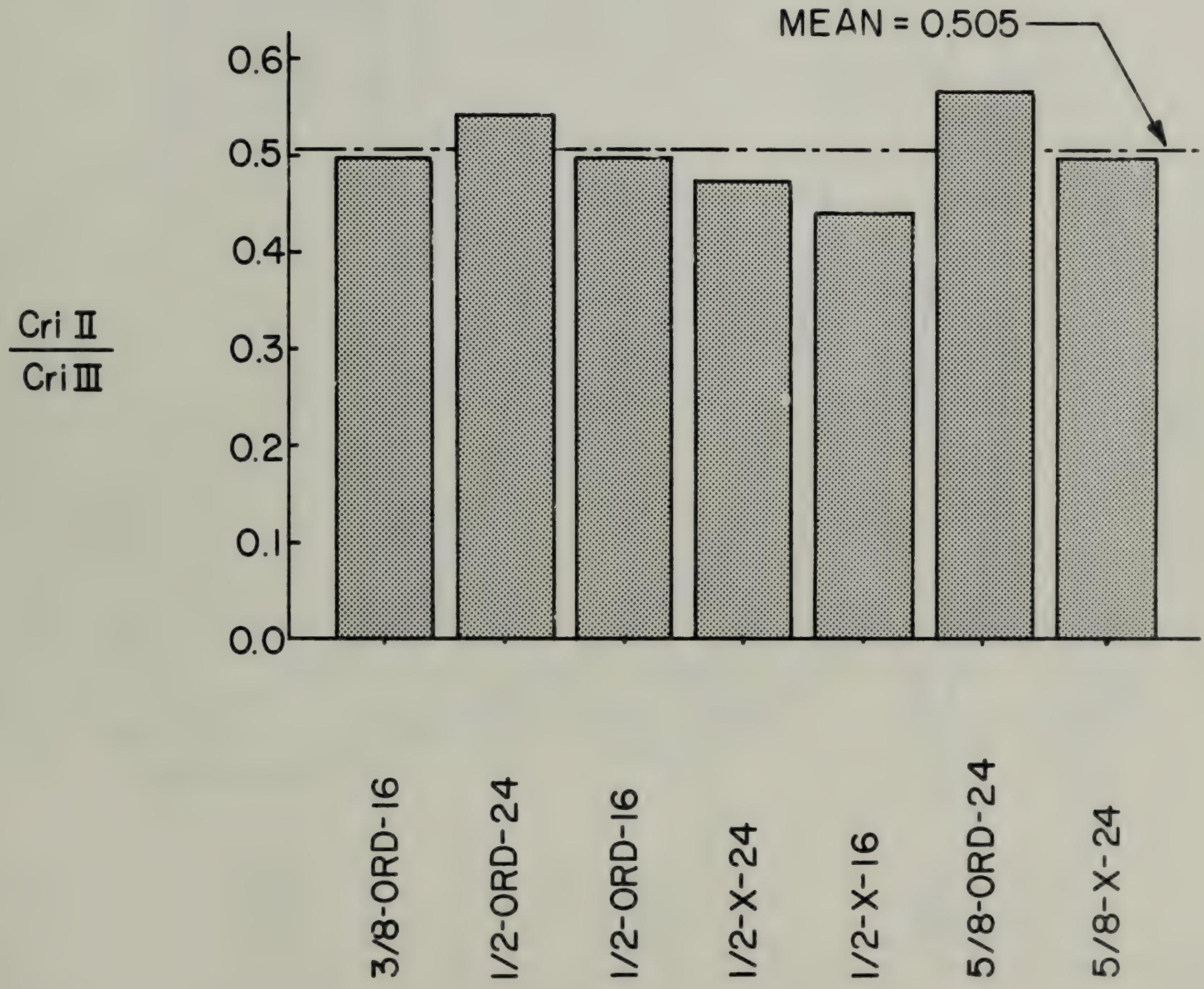

FIGURE 12 RATIOS OF IMPACT STRENGTH FOR CRITERION II TO IMPACT STRENGTH FOR CRITERION III

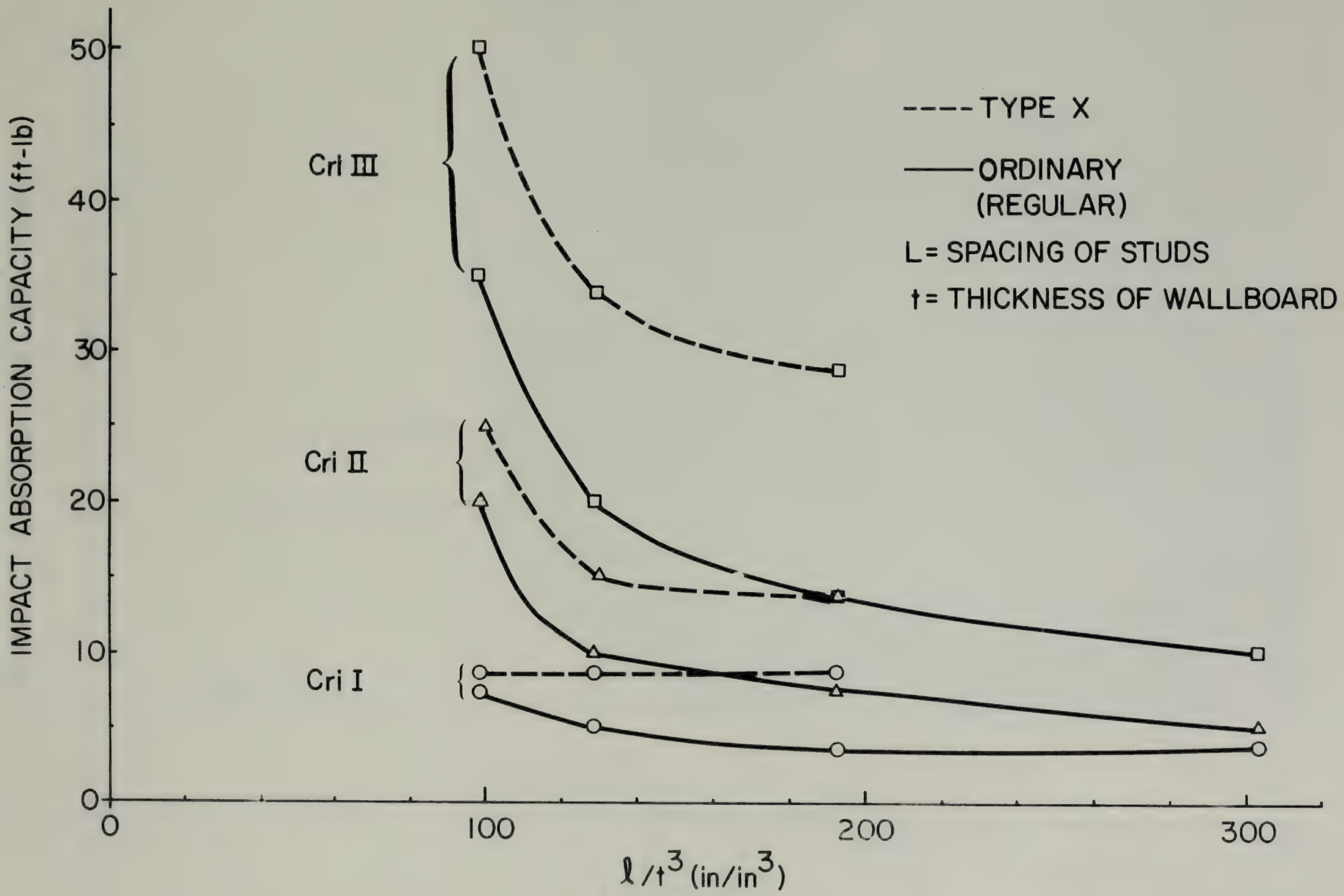

FIGURE 13 EFFECT OF STIFFNESS OF PANEL ON IMPACT STRENGTH

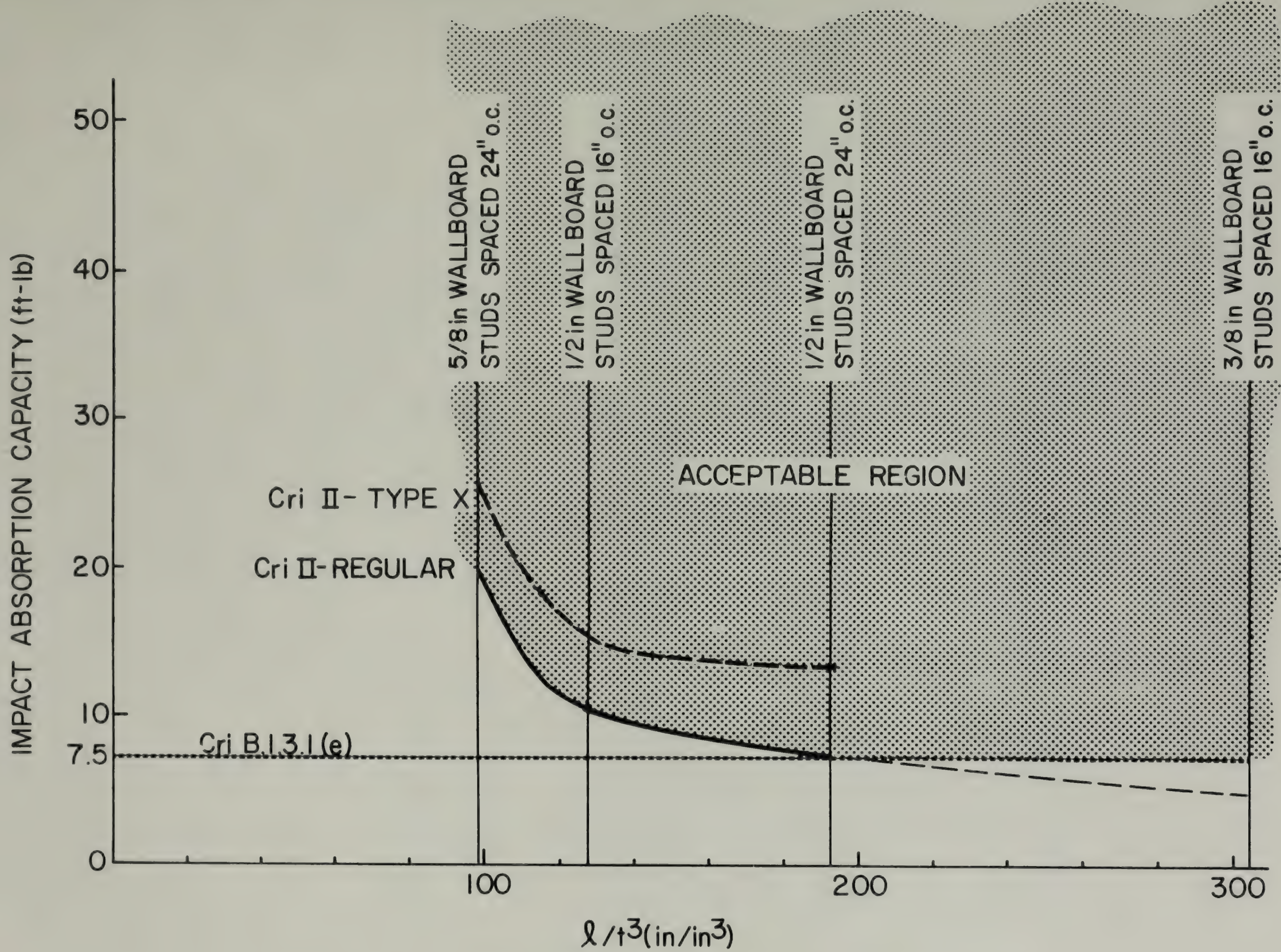

FIGURE 14 COMPARISON OF OPERATION BREAKTHROUGH CRITERION WITH TEST RESULTS

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